Salt movement in a fine-textured processed oil shale under semi-arid conditions

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ABSTRACT

A high soluble salt content in processed oil shales or other mineral wastes can pose problems in vegetation establishment on disposal piles and in water quality of drainage from disposal sites. In this study a fine-textured, saline, processed oil shale was leached or covered with 0.3 m of soil to facilitate vegetation establishment. Salt moved upward into the leached processed shale or into the soil cover during the growing season following vegetation establishment which was facilitated by sprinkler irrigation. After five growing seasons under prevailing climatic conditions averaging 260 mm of precipitation per year the salts had moved downward and soluble salt concentrations in the leached processed shale and soil cover were comparable to the salt concentrations present immediately after these treatments were applied.

Oil shales are found throughout the world and vary considerably in organic carbon content and in inorganic minerals. The oil in oil shale is a solid, complex organic material in an inorganic mineral matrix. Oil shale can be heated (retorted) to volatilise organic compounds which are then condensed to give a liquid crude oil. Research on oil shale mining and retorting has been carried out in the USA sporadically for about seventy years, but only at relatively high oil prices does commercial development appear feasible. Commercial oil shale development is now beginning in the USA, but production of enough oil to have an impact on oil supplies is probably decades away.

Oil shale reserves in the western part of the USA are estimated to contain about $9.5 \times 10^{12}$ litres (600 billion barrels) of recoverable crude oil. This resource is located in arid and semi-arid areas now used largely as range and wildlife habitat. One of the major problems associated with oil shale development will be the environmentally acceptable disposal of massive amounts of processed shale. A mature oil shale industry producing $1.6 \times 10^{8}$ litres/day of oil (one million barrels per day of oil) would generate an estimated $5 \times 10^{8}$ tonnes of processed shale per year. Part of this waste might be returned to mined areas, but a large proportion would require surface disposal.

Part of the solution for the management of processed shales might be the establishment of vegetative cover on disposal piles to control erosion. Also, transpiration by the vegetation would decrease the amount of water available for deep percolation through processed shales which are usually high in soluble salts. Establishment of vegetation would also aid in returning the area to range and wildlife habitat, and provide a more aesthetic landscape.

The physical and chemical characteristics of processed shales depend primarily on the retorting method and on the characteristics of the oil shale. Processed shale produced by some low-temperature retorting processes might be used as plant growth media. Processed shales produced by high-temperature retorting processes have a high pH and are less suitable or unsuitable as plant growth media.

Growth-media limitations in establishing and maintaining vegetation on the low-temperature retorted shales are high soluble salt content, low nitrogen and phosphorus fertility, a dark colour and textures which may be silt or include a high coarse-fragment content. The most extensively reported vegetative stabilisation research on processed shale has been on the silty black spent shale produced by the TOSCO II process, on which plant growth has been reported as ranging from poor to fair.

Approaches to overcoming the problem of high soluble salt content when attempting to establish vegetation on processed shale include leaching or soil cover. Laboratory studies have shown that the bulk of the soluble salts which are dominated by sodium, magnesium, calcium and sulphate ions can be leached from processed shales.

Field studies have demonstrated the net downward movement of soluble salts in coarse-textured processed shales under semi-arid and arid conditions. This article reports on salt movement in a fine-textured processed shale as affected by leaching or soil-cover treatments applied to facilitate vegetation establishment and growth.
MATERIALS AND METHODS

The processed shale used in this study was produced by the TOSCO II process. This is a low-temperature (approx. 500°C) retorting process involving heat transfer to the shale by ceramic balls.\textsuperscript{12} The crushing and retorting results in a black residue which is considerably finer (see Table 1) than spent shales produced by most experimental retorting processes.

Field treatments reported in this study are:

1. Leached processed shale.
2. Unleached processed shale with 0.3 m of soil cover.

Each treatment had a north and south aspect with a 25% slope. Each treatment was replicated. The treatments reported here are a portion of a larger study on which detailed progress reports are available.\textsuperscript{8,13}

The plots were established in 1973 on the US Government’s Anvil Points Experimental Oil Shale facility located about 10 km west of Rifle, Colorado (Figure 1), at an elevation of 1,700 m. Native vegetation in the area is dominated by Utah juniper (Juniperus utahensis) on steeper slopes and shallower soils, and by big sage (Artemisia tridentata) on deeper soils. Details of the plot establishment have been reported,\textsuperscript{4} so that only details directly related to salt movement are reported here. The plots were constructed by initially excavating soil 0.6 m deep from an area 15 m wide by 20 m long, along an east-west axis. The processed shale was dumped into the excavated area and piled in a ridge, then shaped to give south-facing and north-facing slopes. The shaping resulted in processed shale depths of 0.6 m at the toe and 2.4 m at the crest of each plot; the depths of processed shale were 0.3 m less on plots where a 0.3 m soil cover was applied. Individual plots on each aspect were 3.3 m wide and 6.6 m long. Wooden dividers extending from the bottom of the excavation to 8 cm above the surface were used to separate leached from unleached treatments. The only compaction applied to the processed shale was by a small tracked loader used for shaping. The calcareous, non-saline, chernyakh clay loam soil (Torriorthent) from the excavation was used for the 0.3 m soil cover treatment (Table 1).

A sprinkler system with a water application rate of 4 mm/hr was used to leach the processed shale and to irrigate for seedling establishment. This application rate was less than the infiltration rate of the processed shale; thus, no runoff resulted from sprinkling. One metre of water was applied for leaching by running the sprinkler continuously for two five-day periods separated by a four-day ‘rest’ period in May 1973. The water applied had an electrical conductivity of 0.2 to 0.3 dS/m. During the leaching period the 0.3 m of soil cover over unleached shale plots was covered with polyethylene sheeting.

All plots were then fertilised at 400 kg/ha with phosphorus as triple superphosphate which was mixed in to a depth of 10 cm. The plots were then seeded with a mixture of the following species indigenous to the area: Agropyron smithii, A. spicatum, Oryzopsis hymenoides, Atriplex canescens, Artemisia tridentata, Ceroides lanata and Chrysothamnus spp. To ensure seedling establishment, all plots were mulched with hay and then irrigated with a total of 0.5 m of water over the period 12 June to 14 August 1973. The water, applied daily, was calculated to be slightly in excess of the evapotranspiration demand.\textsuperscript{14} Nitrogen was applied after germination at the rate of 66 kg/ha as ammonium nitrate. Maintenance nitrogen at the rate of 66 kg/ha per year was broadcast in April 1974 to 1978. After six growing seasons, nitrogen fertilisation was discontinued. After the irrigation for vegetation establishment in 1973, the vegetation persisted under natural precipitation which averaged 260 mm/yr for the 1974–9 period (Table 2).

Neutron probe access tubes were installed 2.2 m below the crest of each plot to a depth of 1.8 m. The water content of the processed shale and soil was monitored with a neutron probe in the spring and fall and several times during each growing season. Core samples were taken by 15 cm increments to a depth of 1.2 m from 2 to 3 m below the crest of the leached shale plots in June and October of 1973, in May 1974, and on all plots in the fall of 1974, fall and spring of 1975 and fall of 1979. The core samples were air-dried and soluble salt levels were determined by electrical conductivity measurements on extracts from a 1:1 mixture of distilled water and processed shale or soil. The 1:1 ratio was used rather than a saturated paste, because only a limited sample of retorted shale was collected to minimise plot disruption.

Ground cover by living vegetation was estimated at peak phytomass production in 1973 and 1974 by randomly placing four 20 \times 40 cm quadrats on each plot and estimating living vegetative cover. In later years the shrubs became too large to use the quadrant method. Thus, from 1975 to 1979 a line intercept method was used to determine vegetative cover. The procedure for the line-intercept method was to divide each plot by thirds into a lower, middle and upper section. Then a 3.5 m line transect was made by measuring projected ground cover by centimetre increments, by species, along one side of a tape placed on the contour within each section. When there was overlap among species, cover for each species was recorded. Transect increments where there was no living vegetation were also recorded so that total living vegetation ground cover could be calculated.

Electrical conductivity data from the core samples taken in September 1974, November 1975 and September 1979 were subjected to variance analysis. These sampling dates were selected to explore major changes in soluble salt content with time. Additional data on soluble salt content at other sampling dates are also presented to make a more complete picture of profile changes in soluble salt with time for each treatment.

Figure 1  The general location of oil shale deposits in the western United States is indicated by the diagonal lines on the map.